Si/SiGe Superlattices and GaN Nanotubes Fabricated

A team led by Peidong Yang has reported two major advances in the synthesis and characterization of one-dimensional nanotubes and wires. In the first, they grew “superlatticed” nanowires composed of two semiconductors, Si and Si/Ge, arranged in discrete alternating segments. Such nanowires have great potential for applications in electronics because they could function as a transistor, light-emitting diode, biochemical sensor, and heat-pumping thermoelectric device simultaneously. In the second advance, the team grew hollow gallium nitride (GaN) nanotubes for the first time. These materials could have applications in light emitting and nanofluidic devices.

Many integrated circuit technologies (for example, light emitting diodes, laser diodes, and high performance transistors) depend on “heterostructures” of two different semiconductor materials. While there are a number of mature techniques (e.g., molecular beam epitaxy) for the fabrication of 2-D thin film heterostructures and superlattices, a general synthetic scheme for the formation of these structures in 1-D materials with well-defined interfaces has not yet been developed.

The new synthetic approach for 1-D heterostructures is an adaptation of Yang’s own technique of “pulsed laser ablation/chemical vapor deposition” to make single compound nanowires (MSD Highlight 01-8). A silicon wafer coated with a thin layer of gold is heated in a furnace and the gold film breaks up into nanometer-sized droplets. The gaseous Si precursor ($SiCl_4$) is introduced into the growth chamber and the Si dissolves into the gold droplet. Under the appropriate conditions, the Si becomes supersaturated in the Au droplet and begin crystalline growth under it. Long crystalline Si wires, each capped with a gold drop begin to rise. Introduction of Ge vapor periodically by laser ablation of a solid target leads to the insertion of sections of Si/Ge in the wire. The result is the formation of arrays of wires up to several microns long, 50–300 nm in diameter, with an axial composition alternating between pure Si and SiGe in an approximate 90:10 composition ratio.

Gallium nitride is a highly prized semiconductor in the electronics industry because of its unique electronic and optical properties. Although it has been synthesized previously in the form of 1-D nanowires, hollow nanotubes of this material had not been made. To make hollow GaN nanotubes, an “epitaxial casting” technique was employed. Using zinc oxide nanowires (MSD Highlight 01-8) as templates, chemical vapor deposition was used to grow GaN around the ZnO cores. The sample was heated to evaporate the zinc oxide leaving only thermally stable gallium nitride, a high-density, ordered array of nano-sized tubes (see figure).

In ongoing research, the team is working to increase the “sharpness” of the Si/SiGe interfaces of the wires; at present, the transition from the maximum to minimum Ge content occurs over an axial distance of 100 nm. They are also exploring the formation of nanotubes composed of other semiconducting materials besides GaN using the epitaxial casting technique. 1-D structures made by these techniques are expected to have applications in nanosized devices such as p-n junctions, coupled quantum dot structures, and bipolar transistors. In addition, the nanowires can be used as building blocks for constructing more complex systems.

P. Yang, (510) 643-1545, Materials Sciences Division (510 486-4755), Berkeley Lab.

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